IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s): C.I. Podilchuk et al.
Case: 11-1
Serial No.: 09/368,380
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Group: 2613
Examiner: Charles E. Parsons

I hereby certify that this paper is being deposited on this date with the U.S. Postal Service as first class mail addressed to the Assistant Commissioner for Patents, Washington, D.C. 20231.

Signature: Lena K. Haslie Date: February 27, 2003

Title: Method and Apparatus for Dense Motion Field Based Coding

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APPEAL BRIEF

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Applicants hereby appeal the final rejection dated September 27, 2002 of claims 1-8, 11-18 and 21-26 of the above-identified application.

REAL PARTY IN INTEREST

The present application is assigned to Lucent Technologies Inc., as evidenced by an assignment recorded August 4, 1999 in the U.S. Patent and Trademark Office at Reel 010152, Frame 0453. The assignee Lucent Technologies Inc. is the real party in interest.

RELATED APPEALS AND INTERFERENCES

There are no known related appeals or interferences.

STATUS OF CLAIMS

Claims 1-26 are pending in the present application. Each of claims 1-8, 11-18 and 21-26 stands finally rejected under 35 U.S.C. §102(b), §102(e) or §103(a). Claims 9, 10, 19 and 20 are indicated as containing allowable subject matter. Claims 1-8, 11-18 and 21-26 are appealed.

STATUS OF AMENDMENTS

There have been no amendments filed subsequent to the final rejection.

SUMMARY OF INVENTION

The present invention is directed to methods and apparatus for encoding an image sequence.

An illustrative embodiment of the invention as shown in FIG. 2 is in the form of a video coder 100 which includes a dense motion field estimation element 120. The dense motion field estimation element 120 performs dense motion field estimation in accordance with the techniques described on page 6, line 16 to page 13, line 19 of the specification. The resulting motion estimates, e.g., motion vectors, are applied to motion compensator 122 and lossless coder 124 as illustrated in FIG. 2.

In accordance with one aspect of the invention, corresponding generally to independent claims 1 and 11, an estimate of apparent motion within the image sequence is generated utilizing a dense motion field of a portion of the image sequence. The estimate includes a plurality of motion vectors each corresponding to an element of the dense motion field, and is generated at least in part as a constrained function of a characterization of motion between elements of the dense motion field and elements of one or more other portions of the image sequence.

In accordance with another aspect of the invention, corresponding generally to independent claims 21 and 24, an estimate of apparent motion within the image sequence is generated at least in part "utilizing a Markov random field (MRF) model to characterize motion between a given pixel of a motion field and one or more neighbor pixels.

The importance of the claimed invention and its advantages relative to conventional techniques are described in the specification at, for example, page 5, lines 5-18, as follows, with emphasis supplied:

In conventional block-based video encoders, motion vectors are generally based on 16x16 or 8x8 blocks of pixels, since it has been determined that this amount of information can be coded in an efficient manner and sent to the decoder as side information. Although finer motion vectors, e.g., motion vectors based on 4x4 or 2x2 blocks of pixels or on single pixels, provide better prediction, it has heretofore generally been believed that the resulting increased amount of side information cannot be encoded efficiently enough to produce an acceptable level of compression.

The present invention overcomes this problem by utilizing an MRF model which imposes a piecewise smoothness constraint on the motion field. This approach is appropriate since within a given object, it is expected that the motion will be uniform. By forcing the motion field to be smooth using the techniques of the invention, the motion field can be encoded very efficiently. Without this smoothness constraint, i.e., if the dense motion field estimation process simply attempted to find a motion vector for every pixel in the motion field by matching pixel data between frames, the resulting motion vectors would generally be going in many different directions and would therefore be very difficult to encode efficiently.

The above-cited portion of the specification thus indicates that an unconstrained dense motion field estimation process, which generally attempts to find a motion vector for every pixel in the motion field by matching pixel data between frames, is problematic. The present invention provides an efficient solution to this significant problem.

ISSUES PRESENTED FOR REVIEW

1. Whether claims 1-3 and 11-13 are properly rejected under 35 U.S.C. §102(b) as being anticipated by U.S. Patent No. 5,654,771 (hereinafter "Tekalp").

2. Whether claims 21-26 are properly rejected under 35 U.S.C. §102(e) as being anticipated by U.S. Patent No. 6,226,410 (hereinafter "O'Rourke").

3. Whether claims 4-8 and 14-18 are properly rejected under 35 U.S.C. §103(a) as being unpatentable over Tekalp in view of O'Rourke.

GROUPING OF CLAIMS

With regard to Issue 1, claims 1-3 and 11-13 stand or fall together.

With regard to Issue 2, claims 21-26 stand or fall together.

With regard to Issue 3, claims 4 and 14 stand or fall together, claims 5 and 15 stand or fall together, claims 6 and 16 stand or fall together, claims 7 and 17 stand or fall together, and claims 8 and 18 stand or fall together.

ARGUMENT

Issue 1

Applicants initially note that MPEP §2131 specifies that a given claim is anticipated "only if each and every element as set forth in the claim is found, either expressly or inherently described, in a single prior art reference," citing Verdegaal Bros. v. Union Oil Co. of California, 814 F.2d 628, 631, 2 USPQ2d 1051, 1053 (Fed. Cir. 1987). Moreover, MPEP §2131 indicates that the cited reference must show the "identical invention . . . in as complete detail as is contained in the . . . claim," citing Richardson v. Suzuki Motor Co., 868 F.2d 1226, 1236, 9 USPQ2d 1913, 1920 (Fed. Cir. 1989).

Independent claims 1 and 11 stand rejected as being anticipated by Tekalp. Applicants note that each of independent claims 1 and 11 calls for a particular type of motion estimation based on a dense motion field of a portion of the image sequence. These claims each include limitations specifying substantially as follows:

(i) the estimate comprises a plurality of motion vectors each corresponding to an element of the dense motion field; and

(ii) the estimate is generated at least in part as a constrained function of a characterization of motion between elements of the dense motion field and elements of one or more other portions of the image sequence.

For reasons that will be described in greater detail below, Applicants respectfully submit that the Tekalp reference fails to teach or suggest at least the above-noted limitations (i) and (ii) of claims 1 and 11.

As noted previously herein, the use of a conventional unconstrained dense motion field estimation process, which attempts to find a motion vector for every pixel in the motion field by matching pixel data between frames, is problematic. The present invention as set forth in independent claims 1 and 11 overcomes this significant problem by generating the motion estimate "at least in part as a constrained function of a characterization of motion between elements of the dense motion field and elements of one or more other portions of the image sequence." It is this constrained function aspect of dense motion field estimation that is called for in limitation (ii) of claims 1 and 11.

The Examiner in rejecting independent claims 1 and 11 under §102(b) argues that the above-described limitations (i) and (ii) are disclosed by column 2, lines 45-50, and column 8, lines 1-17, respectively, of the Tekalp reference (Final Office Action, page 2, last paragraph and page 3, first paragraph). Applicants respectfully disagree.

The column 2, lines 45-50 portion of the Tekalp reference relied upon by the Examiner as teaching limitation (i) of claims 1 and 11 states as follows:

> Another object of the invention is to provide a data compression system in which dense motion vectors are obtained representing values and directions of motion of the scene content between a temporally second image frame with respect to a temporally first image frame. The term "temporally" is not restricted to order of occurrence of the frames (dense motion estimation).

As indicated above, limitation (i) specifies that the estimate in the claimed invention "comprises a plurality of motion vectors each corresponding to an element of the dense motion field." Applicants submit that this particular limitation is not met by the above-cited portion of the Tekalp reference.

In addition, the column 8, lines 1-17 portion of the Tekalp reference relied upon by the Examiner as teaching limitation (ii) of claims 1 and 11 states as follows:

For a new first image frame, first a motion segmentation algorithm is employed to determine the regions with different motions. Motion segmentation algorithms are known in the art, as for example, described in a publication by J.Y.A. Wang and E.H. Adelson, titled, "Representing moving images with layers," IEEE Trans. Image Proc., vol. 3, no. 5, September 1994, pp. 625-638.

For each segment representing motions at least the following steps are taken:

(a) Get the number of node points, mark all the pixels in the temporarily first frame which fall into the failure regions (BTBC), and fit a polygon around BTBC which determines the initial node points.

(b) Using the dense motion field, compensate the temporarily second frame and find the displaced frame difference (DFD).

Applicants submit that this portion of the Tekalp reference fails to teach or suggest limitation (ii) of claims 1 and 11. As indicated above, limitation (ii) calls for a type of motion estimation in which the estimate "is generated at least in part as a constrained function of a characterization of motion between elements of the dense motion field and elements of one or more other portions of the image sequence." With regard to the above-cited passage from Tekalp, the Examiner states that the passage "clearly indicate[s] . . . that the estimation is done within a constrained area which is synonymous to a constrained function" (Final Office Action, page 2, first paragraph). Applicants respectfully disagree. The claimed "constrained function" is a constrained function <u>of a characterization of motion between elements of the dense motion field and elements of one or more other portions of the image sequence</u>. The claimed "constrained function" is therefore not synonymous with a constrained area based on image segmentation as taught by Tekalp.

It appears that Tekalp teaches to generate a dense motion field in a conventional manner (column 7, lines 6-13), and then to apply an image segmentation algorithm (column 8, lines 1-3) followed by a triangulation algorithm for each segment (column 8, lines 33-37) in order to obtain a more efficient representation of the dense motion field. The above-cited portion of Tekalp from column 8, lines 1-17 refers to an exemplary segmentation algorithm, and fails to meet limitation (ii) as alleged by the Examiner.

The Examiner further states as follows in the Advisory Action dated January 14, 2003, with regard to the "constrained function" of limitation (ii):

> The claims do not reflect the specific constrained function as argued by the Applicant. As it appears in the claims, a constrained function can be interpreted as any mathematical function that is bounded by certain limitations such as an integral function with finite limits set in order to define an area under a curve or an area within a frame that contains dense motion such as in the referenced prior art.

Applicants believe that the Examiner is incorrect in the foregoing assertions. The claim language at issue does not simply refer to a constrained function *per se*, but instead more particularly calls for a constrained function of a characterization of motion between elements of the dense motion field and elements of one or more other portions of the image sequence. The claimed constrained function is simply not present in Tekalp.

Applicants therefore submit that independent claims 1 and 11 are not anticipated by the Tekalp reference.

Dependent claims 2, 3, 12 and 13 are believed allowable for at least the reasons identified above with regard to their respective independent claims.

Issue 2

Independent claims 21 and 24 stand rejected under §102(e) as being anticipated by O'Rourke. Applicants note that each of these claims calls for, in encoding an image sequence, generation of an estimate of apparent motion within the sequence, "wherein the estimate is generated at least in part utilizing a Markov random field (MRF) model to characterize motion between a given pixel of a motion field and one or more neighbor pixels." The Examiner argues that such an arrangement is disclosed in O'Rourke. Applicants respectfully disagree. The Examiner cites column 4, line 67 to column 6, line 60 of O'Rourke in conjunction with FIGS. 3A and FIG. 7 as providing the teachings (Final Office Action, pages 4 and 5). However, the reference to Huber Markov random field (HMRF) in the column 4, line 67 to column 5, line 36 portion of O'Rourke relates to decoding of

a previously-encoded image sequence, and not to <u>encoding</u> of the image sequence as claimed. This is apparent from column 4, lines 53-58 of O'Rourke, which states as follows, with emphasis supplied:

> The <u>decompression</u> techniques implemented in the present invention will now be described in detail. To <u>decompress</u> the compressed image representation, a maximum a posteriori ("MAP") technique is used. The decompressed full resolution image is represented by z.

It is therefore clear that at least a portion of the cited passage relied on by the Examiner in formulating the §102(e) rejection relates to the use of the HMRF in a decoding process.

In addition, the reliance by the Examiner on FIG. 3A is misplaced. FIG. 3A shows "a block diagram of the encoder filter 300 used to calculate a sequence of step sizes," as indicated in column 5, lines 36-38. It fails to teach or suggest an encoder which generates an estimate of apparent motion within a sequence "wherein the estimate is generated at least in part utilizing a Markov random field (MRF) model to characterize motion between a given pixel of a motion field and one or more neighbor pixels," as claimed.

Moreover, Applicants note that the motion estimation process implemented by FIG. 7 of O'Rourke is a type of conventional block-based motion estimation, such as that described by Applicants in the background portion of their specification. This is apparent from column 10, lines 7-62, wherein it is more particularly stated at lines 41-43 that "the motion estimator 755 generates a motion vector . . . for each block or macro-block of the current frame."

O'Rourke therefore teaches block-based motion estimation, and fails to teach or suggest the claimed generation of an estimate of apparent motion within an image sequence, "wherein the estimate is generated at least in part utilizing a Markov random field (MRF) model to characterize motion between a given pixel of a motion field and one or more neighbor pixels."

Applicants therefore respectfully submit that independent claims 21 and 24 are not anticipated by O'Rourke.

Dependent claims 22, 23, 25 and 26 are believed allowable for at least the reasons identified above with regard to their respective independent claims.

Issue 3

Dependent claims 4-8 and 14-18 stand rejected under 35 U.S.C. §103(a) as being unpatentable over Tekalp in view of O'Rourke. Applicants initially note that each of these claims is believed to be allowable for at least the reasons identified above with regard to their respective independent claims. Moreover, as indicated previously, each of the claim pairs 4 and 14, 7 and 17, and 8 and 18 is believed to define separately patentable subject matter, as outlined below.

With regard to claims 4 and 14, these claims relate to a particular characterization of motion in motion estimation of an encoding process. More specifically, these claims specify that the "characterization" associated with the constrained function of claims 1 and 11 is "based on a multiscale data model which characterizes the motion as a Markov random field (MRF)."

As indicated above, the reference to HMRF in O'Rourke relates to a decoding process. Applicants therefore submit that there is no motivation for the combination of Tekalp and O'Rourke proposed by the Examiner. In other words, one skilled in the art would not be motivated to take an element of the decoding teachings of O'Rourke for use in the encoding process as claimed, particularly in view of the fact that O'Rourke itself fails to use the HMRF in its encoding process.

The Examiner has failed to identify any cogent motivation for the proposed combination, instead simply stating that "it would have been obvious" because "both inventions estimate motion using dense motion fields" and the use of Markov random fields was well known in the art at the time the invention was made (Final Office Action, page 6, first paragraph).

The Federal Circuit has stated that when patentability turns on the question of obviousness, the obviousness determination "must be based on objective evidence of record" and that "this precedent has been reinforced in myriad decisions, and cannot be dispensed with." In re Sang-Su Lee, 277 F.3d 1338, 1343 (Fed. Cir. 2002). Moreover, the Federal Circuit has stated that such "conclusory statements" by an examiner fail to adequately address the factual question of motivation, which is material to patentability and cannot be resolved "on subjective belief and unknown authority." Id. at 1343-1344.

Applicants submit that the conclusory statement of obviousness provided by the Examiner in the first paragraph of page 6 of the final Office Action is based on the type of "subjective belief and unknown authority" that the Federal Circuit has indicated as providing insufficient support for an obviousness rejection.

In addition, even if one assumes for purposes of argument that Tekalp and O'Rourke are combinable in the manner proposed by the Examiner, the combination fails to teach or suggest all of the limitations of the claims. For example, there is no teaching in either reference regarding the claimed multiscale data model.

With regard to claims 5 and 15, these claims further specify that the multiscale data model characterizes at least one of spatial coherence, temporal coherence and scale coherence of the dense motion field. The Examiner argues that such an arrangement is met by the combined teachings of Tekalp and O'Rourke, and more particularly by column 6, lines 45-65 of Tekalp (Final Office Action, page 6, second paragraph). Applicants respectfully disagree, and can find no teaching or suggestion in the cited portion of Tekalp regarding the particular limitation in question. The O'Rourke reference is similarly deficient with regard to this limitation. Moreover, as indicated previously, the Tekalp and O'Rourke references are not combinable in the manner proposed by the Examiner.

With regard to claims 6 and 16, these claims further specify that the multiscale data model allows a motion vector at a coarse scale to represent an average motion over a set of pixels from a given image of the sequence to another image of the sequence. The Examiner argues that such an arrangement is met by the combined teachings of Tekalp and O'Rourke, and more particularly by column 6, lines 25-60 of O'Rourke (Final Office Action, page 6, third paragraph). Applicants respectfully disagree, and can find no teaching or suggestion in the cited portion of O'Rourke regarding the particular limitation in question. The Tekalp reference is similarly deficient with regard to this limitation. Moreover, as indicated previously, the Tekalp and O'Rourke references are not combinable in the manner proposed by the Examiner.

With regard to claims 7 and 17, these claims further specify that the multiscale model utilizes higher order potential functions to characterize structural properties of the dense motion field, and singleton potential functions to characterize the manner in which observations of particular types of

dense motion fields affect the likelihood with which such fields occur. The Examiner argues that such an arrangement is met by the combined teachings of Tekalp and O'Rourke, and more particularly by column 5, lines 8-54 of O'Rourke (Final Office Action, page 6, fourth paragraph). Applicants respectfully disagree, and can find no teaching or suggestion in the cited portion of O'Rourke regarding the particular limitation in question. The Tekalp reference is similarly deficient with regard to this limitation. Moreover, as indicated previously, the Tekalp and O'Rourke references are not combinable in the manner proposed by the Examiner.

With regard to claims 8 and 18, these claims specify that the constrained function of claims 1 and 11, respectively, comprises a first maximum *a posteriori* (MAP) estimation problem with a constraint on the entropy of the desired estimate. The Examiner argues that such an arrangement is met by the combined teachings of Tekalp and O'Rourke, but does not identify with sufficient particularity the portion of either reference which is alleged to show the claimed arrangement (Final Office Action, page 6, fifth paragraph). Applicants submit that the limitation regarding a MAP estimation problem with a constraint on entropy as set forth in claims 8 and 18 is not met by the use of MAP estimation in decoding as taught by O'Rourke. The Examiner is taking decoding teachings from O'Rourke and arguing that they are readily combinable with the encoding process of Tekalp. However, there is no motivation identified for taking the O'Rourke teachings out of their decoding context in this manner.

In view of the foregoing, Applicants believe that claims 1-8, 11-18 and 21-26 are in condition for allowance, and respectfully request the withdrawal of the §102(b), §102(e) and §103(a) rejections.

Respectfully submitted,

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APPENDIX

1. A method for encoding an image sequence, the method comprising the steps of:

generating an estimate of apparent motion within the image sequence utilizing a dense motion field of a portion of the image sequence, wherein the estimate comprises a plurality of motion vectors each corresponding to an element of the dense motion field, and is generated at least in part as a constrained function of a characterization of motion between elements of the dense motion field and elements of one or more other portions of the image sequence; and

utilizing the estimate to perform motion compensation on at least one of the images of the image sequence.

2. The method of claim 1 wherein the image sequence comprises a sequence of video frames.

3. The method of claim 1 further including the step of encoding the estimate such that the estimate may be transmitted to decoder for use in decoding encoded versions of one or more of the images of the sequence.

4. The method of claim 1 wherein the characterization is based on a multiscale data model which characterizes the motion as a Markov random field (MRF).

5. The method of claim 4 wherein the multiscale data model characterizes at least one of spatial coherence, temporal coherence and scale coherence of the dense motion field.

6. The method of claim 4 wherein the multiscale data model allows a motion vector at a coarse scale to represent an average motion over a set of pixels from a given image of the sequence to another image of the sequence.

7. The method of claim 4 wherein the multiscale model utilizes higher order potential functions to characterize structural properties of the dense motion field, and singleton potential functions to characterize the manner in which observations of particular types of dense motion fields affect the likelihood with which such fields occur.

8. The method of claim 1 wherein the constrained function comprises a first maximum *a posteriori* (MAP) estimation problem with a constraint on the entropy of the desired estimate.

9. The method of claim 8 wherein the generating step further includes the step of transforming the constrained function into a second MAP estimation problem having at least one parameter uniquely determined by the entropy constraint, wherein the entropy constraint is determined by an amount of bandwidth available for encoding the image sequence.

10. The method of claim 9 wherein a solution of the second MAP estimation problem minimizes a singleton potential function subject to the entropy constraint, wherein the entropy constraint is computed based on one or more higher order potential functions.

11. An apparatus for encoding an image sequence, the apparatus comprising:

a motion estimator operative to generate an estimate of apparent motion within the image sequence utilizing a dense motion field of a portion of the image sequence, wherein the estimate comprises a plurality of motion vectors each corresponding to an element of the dense motion field, and is generated at least in part as a constrained function of a characterization of motion between elements of the dense motion field and elements of one or more other portions of the image sequence; and

a motion compensator having an input coupled to an output of the motion estimator, and operative to utilize the estimate to perform motion compensation on at least one of the images of the image sequence.

12. The apparatus of claim 11 wherein the image sequence comprises a sequence of video frames.

13. The apparatus of claim 11 further including a lossless coder for encoding the estimate such that the estimate may be transmitted to decoder for use in decoding encoded versions of one or more of the images of the sequence.

14. The apparatus of claim 11 wherein the characterization is based on a multiscale data model which characterizes the motion as a Markov random field (MRF).

15. The apparatus of claim 14 wherein the multiscale data model characterizes at least one of spatial coherence, temporal coherence and scale coherence of the dense motion field.

16. The apparatus of claim 14 wherein the multiscale data model allows a motion vector at a coarse scale to represent an average motion over a set of pixels from the given image to another image of the sequence.

17. The apparatus of claim 14 wherein the multiscale model utilizes higher order potential functions to characterize structural properties of the dense motion field, and singleton potential functions to characterize the manner in which observations of particular types of dense motion fields affect the likelihood with which such fields occur.

18. The apparatus of claim 11 wherein the constrained function comprises a first maximum *a posteriori* (MAP) estimation problem with a constraint on the entropy of the desired estimate.

19. The apparatus of claim 18 wherein the motion estimator is further operative to transform the constrained function into a second MAP estimation problem having at least one parameter uniquely determined by the entropy constraint, wherein the entropy constraint is a function of an amount of bandwidth available for encoding the image sequence.

20. The apparatus of claim 19 wherein a solution of the second MAP estimation problem minimizes a singleton potential function subject to the entropy constraint, wherein the entropy constraint is computed based on one or more higher order potential functions.

21. A method for encoding an image sequence, the method comprising the steps of:

generating an estimate of apparent motion within the sequence, wherein the estimate is generated at least in part utilizing a Markov random field (MRF) model to characterize motion between a given pixel of a motion field and one or more neighbor pixels; and

utilizing the estimate to perform motion compensation on at least one of the images of the sequence.

22. The method of claim 21 wherein the estimate comprises a plurality of motion vectors, with each of the motion vectors corresponding to a pixel of the motion field.

23. The method of claim 21 wherein the neighbor pixels comprise at least one pixel in the same image as the given pixel, at least one pixel in a previous image of the sequence, and at least one pixel of a subsequent image of the sequence.

24. An apparatus for encoding an image sequence, the apparatus comprising:

a motion estimator operative to generate an estimate of apparent motion within the sequence, wherein the estimate is generated at least in part utilizing a Markov random field (MRF) model to characterize motion between a given pixel of a motion field and one or more neighbor pixels; and

a motion compensator having an input coupled to an output of the motion estimator, and operative to utilize the estimate to perform motion compensation on at least one of the images of the sequence.

25. The apparatus of claim 24 wherein the estimate comprises a plurality of motion vectors, with each of the motion vectors corresponding to a pixel of the motion field.

26. The apparatus of claim 24 wherein the neighbor pixels comprise at least one pixel in the same image as the given pixel, at least one pixel in a previous image of the sequence, and at least one pixel of a subsequent image of the sequence.